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Analysis and simulation on rural energy–economy system on Shouyang County in China

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Abstract

A basic feedback structure of rural energy–economy system is approached in this paper based on systems engineering and system dynamics (SD) principles. The dynamics simulation model in then developed and applied in analyzing the energy construction of Shouyang County, Jiangsu Province in China. Consequently, some related policies and measures are proposed.

Keywords: Energy supply; Energy Playing; System dynamics; Simulation; Renewable energy

Contents

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1. Introduction

The energy problem in rural area is a common one for all developing countries in the world at present. The backwardness in economy in rural area resulted in no commercial energy supply for the long past [1–3]. The rural areas mainly depend biomass energy (straw and stalks) and other energy available locally [4]. Therefore, there have been very few developing countries that listed rural energy consumption in their energy program over a long time in the past. The excessive use of local energy resources for some regions has led to the destruction of their ecological environment to a certain extent due to growing population and shortage of natural resources.

The rural energy consumption in China showed some common patterns with other developing countries. Large scale studies on rural energy consumption, especially for household, started from the middle of 1970s in China [5]. A nation wide investigation conducted in 1979 showed that 47.7% of rural households had no enough fuel available for 3–6 months and the ratio of energy supply to demand was 22%. A cooperative sample survey and on-the-spot investigation by Agricultural Ministry, Forestry Ministry of China and ESMAP (Energy Sector Management Assistance Program organized by the World Bank, United Nations Development Program, etc.), carried out from 1987 to 1991 in Hengnan County of Hunai Province, Xiushui County of Jiangxi Province, Kezuo County of Liaoning Province, Jianyang County of Sichuan Province, Changshu County of Jiangsu Province, and Huantai County of Shangdong Province, showed that big differences existed in rural household energy consumption amount and pattern among different regions, and these differences mainly depended on the availability of the local energy [6]. The annual household energy consumption was about 700–1200 kgce (we use 7000 kcal/kgce), 40–60% of which was used for cooking, and 60–90% was biomass energy. The heat efficiencies of stoves were 10–20% [7].

In China, the energy supply in rural areas depends largely upon local natural resources, especially biomass, rather than commercial goods. In the 1980s, the rural economy was reformed successfully, which caused a continuous change in energy supply and consumption. The demand of commercial energy goods grows steadily [8].

Rural energy construction is the basis of ensuring the stable development of local economy. It promotes economy developing and is in turn speeded up by the developed. Therefore, the behavior and characteristics of rural energy–economy system and the related policies as well as measures should be studied according to local population, natural resources and productive potentialities, etc. [9,10]. A simulation on rural

energy–economy system on county-level in China also will help to draw up properly an energy program which enables a harmonic development of social, economic and environmental elements for rural areas

2. Description of Shouyang County

Sheyang County is one of the counties of Jiangsu Province witch is located in the lower reaches of the Yangtse and Huaihe Rivers, close to Zhejiang and Shandong Provinces and Shanghai City. The total area of the County is 2795 km^2, and 82, 18% of the terrain are flatlands and waters, respectively. The County belongs to the subtropical and temperate zones with a monsoon climate, featuring abundant solar energy and rainfall. Statistical data are shown that the total cultivated area is 105,880 ha, the total population, the rural population and the rural households in 2000 were 1,018,872, 871,172 and 312,800, respectively. The population density in the rural areas was 341.5 persons/km^2.

Along with the social and economic development of the County as a result of reform and 'the Open to the World' policy, agriculture and rural economy show generally good characteristics, with bumper harvests for several years running and a fast but steady growth of rural industry. GDP in rural areas in 2000 was 1,416,000,000 RMB and 60.3, 26.3, 5.0, 2.6 and 5.8% are rural industry, farming (including of forestry, animal husbandry, fishery), rural construction, rural transportation and rural wholesales, retail, restaurant, etc. respectively.

The statistical data for the County in 2000 from sampling survey results of 300 rural households show that the persons per household was 2.78, the cultivated land per capita was 0.12 ha and the net income was 2841 RMB yuan (about 346 US$).

The main economic industry is mostly agriculture and the main agriculture products are grain and cotton. In recent years, it developed rapidly. Energy shortages became severe with growing rural enterprises and rising living standards. Biomass may be obtained locally but commercial energy must be supplied from outside. In order to construct a long-term energy strategy, it is important to assess rural domestic energy consumption in the county.

3. Energy consumption in rural areas

3.1. Household energy use

Energy for household use is one of the major parts of rural energy consumption in the County. The total household energy consumption in 2000 was 236,100 tce (Table 1), of which about 82.9% was from straw and stalk. So straw and stalk is the most important fuel. Household energy consumption per capita was 271.0 kgce.

According to the situation in rural households in Sheyang County, the utilization efficiency of effective energy by firewood stove is 20% and by briquette stove 28%, the comprehensive heat exchanging rate by biogas is 36%, and the heat efficiency by LGP is

Table 1
Household energy consumption for Sheyang County in 2000

	1000 tce	%
Straw and stalk	108.8	46.1
Firewood	87.0	36.8
Biogas	5.0	2.1
Coal	16.2	6.9
Electricity	8.9	3.8
LPG	9.3	3.9
Oil	0.9	0.4
Total	236.1	100.0

Electrical energy includes the energy required to produce electricity (1 kWh = 0.404 kgce).

60%. Thus, each person can averagely acquire 59.2 kgce effective cooking energy per year. It indicates that the effective energy demand for rural households in Sheyang has been met.

3.2. Use of energy in production

Energy used by rural production in Sheyang in 2000 was about 710,000 tce, of which only 28.8% by agricultural production, and 71.2% by town and village enterprises (TVEs) (Table 2).

In 2000, the total energy consumption in agricultural production was 204,600 tce, mainly including irrigation and drainage, field operation, processing of agricultural products and its by-products, and agricultural transportation. Energy intensity in agricultural sector was 0.55 tce per 10,000 Chinese yuan of output value.

The total output value of TVEs for Sheyang was 5.64×10^9 RMB in 2000, 46.2% of the total industrial output. Energy used by TVEs was 505,400 tce, including 323,600 Mtce coal and coke (64%), 153,000 tce fuel oil (30.3%) and 11,800 tce electricity (3.6%). Energy intensity in TVEs sector was 1.1 tce per 10,000 Chinese yuan, lower than the average energy intensity level of the whole industrial sector. Energy resources were used mainly in construction materials, machinery, textile and chemical products. Study shows (Tables 3 and 4) the energy intensity by TVEs was lower than that of county governmental enterprises. The reason might be that most TVEs are traditional little energy-consumed; but the energy consumption per unit product in TVEs is mostly higher that that in

Table 2
Energy used by rural production in Sheyang County in 2000

	Coal	Fuel oil	Electricity	Firewood	LPG	Total
Agriculture						
1000 tce		179	25.6			204.6
%		87.5	12.5			100.0
TVEs						
1000 tce	323.6	153.0	10.8	17.0	2.0	506.4
%	66.9	30.2	2.1	3.4	0.4	100.0

Table 3
Energy consumption by production in five counties in Sheyang County in 2000

	Total	Agriculture	County governmental		TVEs	
			Industry	Other enterprises	Industry	Other enterprises
EC[a]	155.54	20.46	65.54	19.00	34.86	15.68
EI[b]	1.49	0.55	2.73	0.79	0.73	1.87

[a] Energy consumption, 10,000 tce.
[b] Energy intensity, 1 tce/10,000 yuan.

government enterprises, because both the energy utilization efficiency and investment for energy saving program in TVEs are lower than the latter.

High energy consumption and the high cost of energy supply have made it essential to save energy for the county level industry. But the scattering factories, the lack of information and technicians have made it difficult for the TVEs to save energy. Therefore, it is necessary to establish service system for energy saving to cover the whole region. Some of the good measures are: to set positions of energy saving (or environment protection, if necessary) manager in rural enterprises or governments, which can fulfill the tasks assigned by the supervision and management, and direct the energy saving project in related enterprises; to train the supervisors, the energy managers and the workers periodically so as to improve the personnel's quality; to set quota for the heavy energy consumers and examine them periodically; to establish star enterprises of energy saving as good examples to improve the level in the whole area.

3.3. Factors affecting rural energy consumption

Although the amount and varieties of rural energy consumption in Jiangsu Province are affected by many factors, such as local energy availability, income, the quantity of live pigs, energy consumption patterns energy costs, and so on, the stability of local energy resources and supply is the main factor. Typical investigation in developed regions showed that most rural households would mainly rely on biomass energy for quite a long period in the future in spite of increasing use of commercial energy.

The attitude towards and comments on each energy resource is the main factor that determines what kind of energy is used. An investigation in Changshu and Yangzhong counties in Jiangsu province shows that LPG is the most favorable one. It is not only

Table 4
Energy intensity of important industries of two counties in Sheyang County (tce/10,000 yuan)

	County governmental	TVEs
Cement	2.37	3.29
Textile machinery	0.58	
Textile	0.43	
Chemical	2.32	0.13
Building materials	2.45	

because LPG is convenient, clean and comfortable, but also because fewer attentions are now paid to the cost due to increased income and improved living conditions. So the high price and the insufficient supply do not prevent peasants from buying and using gas.

In recent years, the increase of household electricity demand is higher than the average energy increasing rate (the present electricity consumption is 15–20 kWh per capita per year). The flexibility between the average level of electricity consumption and the income is obviously greater than that of the average level of total energy and total income. The increase of the electricity consumption in a family is due to the increased electric equipment. Such electrical units as black and white TVs and electric fans are now popular in rural areas. However, with the popularization of color TVs, electric cookers and washing machines, the household electricity consumption level will increase rapidly.

As a large amount of labor rushed into rural enterprises, and part of household energy consumption in former times has been transferred into the work place, the household energy consumption relatively decreases and in turn the industrial energy consumption increases. Such 'transferring' phenomenon exists differently in Jiangsu Province, and it may cause a decrease of the actual demand for rural household energy.

4. Analysis on the basic feedback structure of rural energy–economy system

According to the relations of energy supply with energy consumption, there exists a basic structure with two positive feedback circuits of energy production and energy consumption (Fig. 1).

In Fig. 1, energy construction includes multilevel exploitation and utilization of bioenergy, the construction of commercial energy bases and external energy cooperation; fixed asset represent the designed productivity of the investment; the practical productivity is the effect under inputting energy and some productive factors.

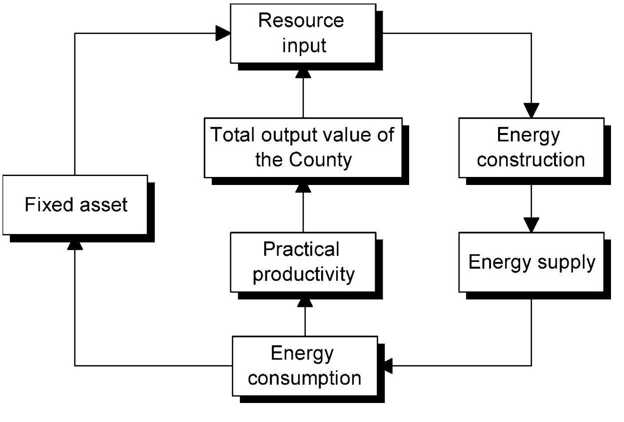


Fig. 1. The basic structure with two positive feedback circuits of energy production and energy consumption.

4.1. Characteristics of the basic feedback structure of rural energy–economy system

The two coupling feedback circuits are amplified by each other. That is to say, while the economy is developed, the basic construction is expanded; productivity and output value are increased. Meanwhile, the increased energy demand remand in investment and energy supply increasing. Consequently, the output value stimulated was further raised. According to the above behaviors, so long as imputing the related productive factors to the system constantly, local economy will keep steady developing except the interference of some non-economical factors.

4.2. Coordinate condition of the two feedback circuits

The coordination of the two feedback circuits is very critical. Any one's advance would cause the investment idle and waste. Only when the ratio of resource input for the two circuits is reasonable can a good economic circle be formed. However, the present situation is neglecting energy construction but concentrating on short-term economic interests. As the two feedback circuits become unbalanced, and finally lead to macro dislocation.

In order to eliminate the vicious circle, the government has taken a lot of measures. Unfortunately, as the time lag is widely existed in the system, economic fluctuation is inevitable. As a result, the system structure must be adjusted to coordinate the two feedback circuits through micro controlling.

5. Model development and its function

The rural energy–economy system is divided into seven subsystems shown in Fig. 2. The subsystems are mutually affected and form an organic whole.

Farm production subsystem not only provides food and industrial raw materials, but also is the important resource of energy consumption. Rural energy consumption of about 86.5% for daily life comes from crop straw. The development of crop production, which provides crop straw, is affected by:

(1) Ecological environment. The crop yield per unit land cultivated has a limited increasing tendency and an obviously progressive repayment decrease.
(2) The lower input–output ratio of agriculture. For the open system, there is no adequate inputting to farm production the three positive feedback circuits (Fig. 3). As a result, the government is expected to guide the correct resource input through some policies.

Industry is the key of local economy. It may support agriculture and is also a big energy-consumption subsystem as shown in Fig. 4, in which the output value income and investment form a positive circuit. In accordance with the surrey to the industry subsystem of Shouyang County, the ratios of output value and energy consumption are quite different among enterprises. For example, the ratio of output value for rural light and heavy industry is 6:4; where as the ratio of energy consumption is 3:7. A large number of small brick kilns

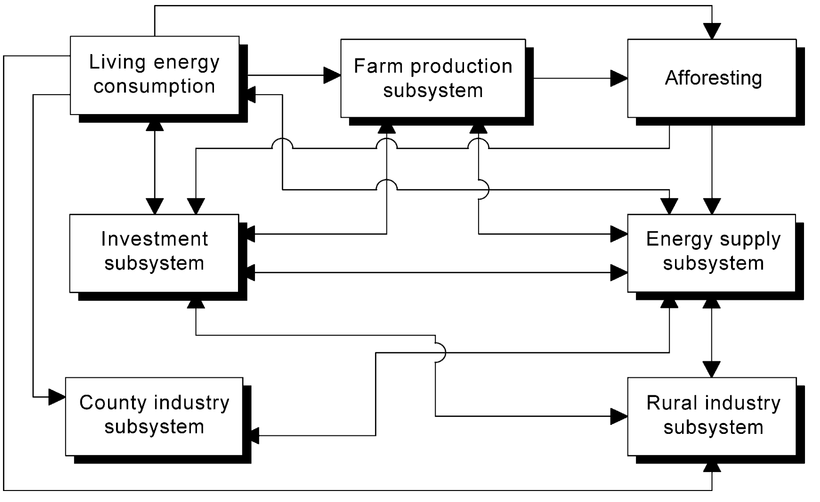


Fig. 2. The rural energy–economy seven subsystems divided and relationship each other.

with high-energy consumption but poor profit has commercial energy and crop straw. In order to solve the above problems, the structure must be adjusted to raise energy input profit by technical reform and management.

In living energy consumption subsystem, city depends on 58.8% of living energy is bioenergy and 76% of crop straw produced is burnt, in which 60% for family cooking. The development of economy increases the commercial energy demand. Meanwhile, the shortage of living fuel pushes the popularization of the energy-saving stoves forward.

Therefore, the bioenergy shortage and the number of energy-saving stoves forms a negative feedback circuits (Fig. 5).

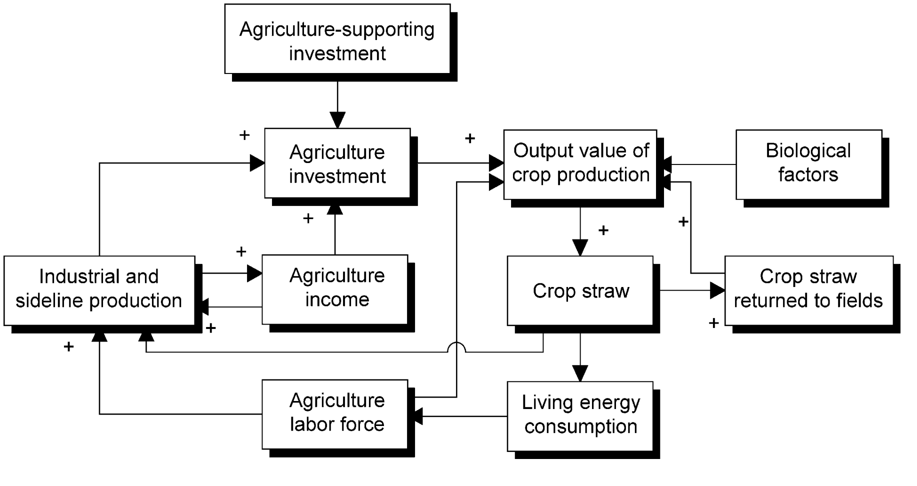


Fig. 3. Farm production subsystem and its construction.

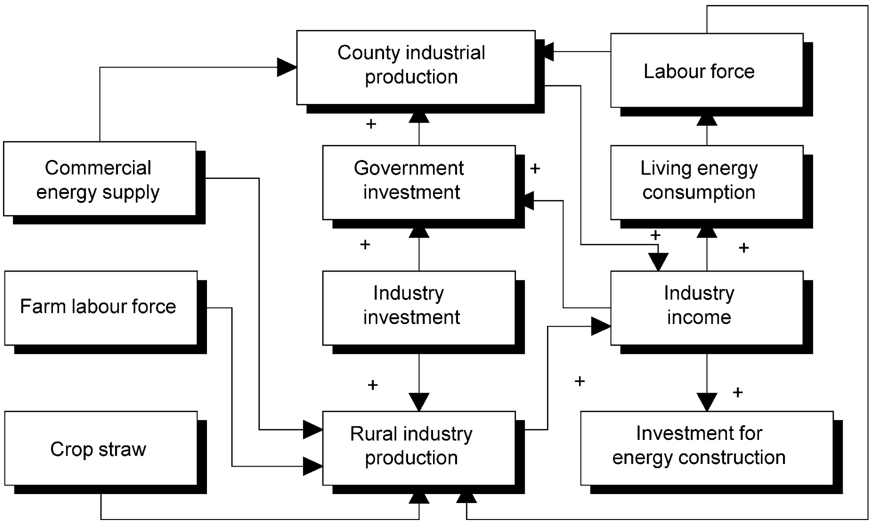


Fig. 4. The industry subsystem and its construction.

In energy supply subsystem, bioenergy comes from farm production, and commercial energy is from government allocation, self-generating and external cooperation. The increasing energy shortage speeds up the energy investment and energy supply. A negative feedback circuit is thus formed.

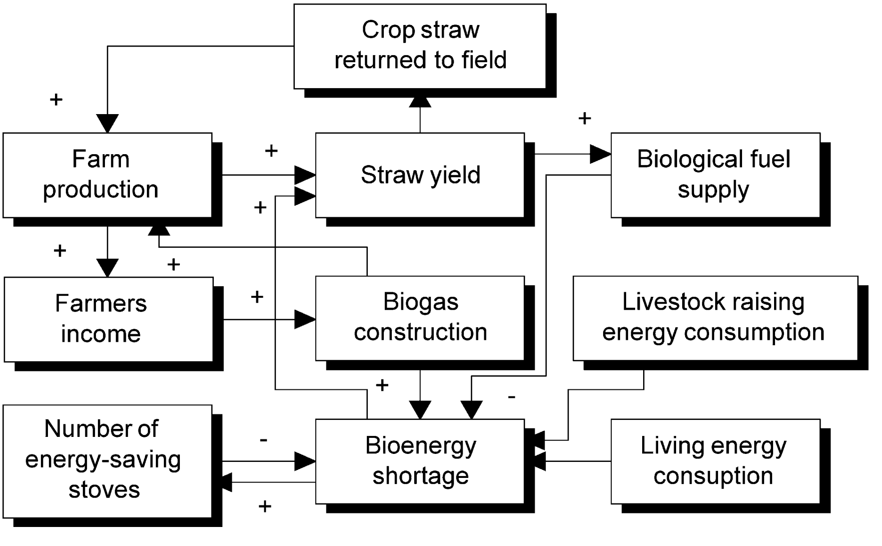


Fig. 5. The living energy consumption subsystem and its construction.

6. Model application, policy experiment and suggestion

According to the rural energy–economy system of Shouyang County, a simulation model is developed to system. The parameters in the model have been acquired after data processing, and the model has been adjusted repetitiously and verified in many aspects, which can well reflect the real situation of the county. Based on the model, we carried out simulation experiments on improved stoves, on popularizing breeding pigs with raw forage, and on saving energy in township and village enterprises and on developing biogas digesters.

Policy experiment 1 simulates the developing tendency of the present structure and policies, whereas experiments 2–5 make a comprehensive analysis for several programs based on experiment l.

In experiment 2, suppose the policy of popularizing high efficiency energy-saving stoves is adopted, by which the heat efficiency is raised from 20 to 25%. The results in Table 5 show that the total commercial energy demand for rural living has a decreasing tendency. Popularizing energy-saving stoves can largely promote the development of local economy. Comparing to the result of experiment l, the agriculture and County's total output value will increase by 26.5 million Yuan and 298.6 million Yuan respectively by the year 2015.

The conventional pig-raising method consumes great amount of living fuel. In experiment 3, suppose pig feed will be uncooked after 2000. The simulation results in Table 6 show that the bioenergy supply before 2005 will meet the demand and rural commercial energy requirement will be largely decreased. However, this measure may cause negative effect around 2010. That is, the bioenergy shortage will decreased by 12,000 tce and rural commercial energy demand will be increased by 12,000 and 11,200 tce. Better energy-saving effect can be achieved again till the end of this century.

Table 5
Energy and economic benefits of developing improved stoves (10,000 yuan)

	Gap of bio-mass energy	Commercial energy consumption in all County	Gross output value of farming	Gross output value of town and village enter-prises	All GDP
2005	−3550	−2309	+240	+1600	+2650
2010	−13,340	−8733	+505	+4290	+7060
2015	−17,020	−11,099	+1697	+26,890	+29,860

Table 6
Energy benefits on popularizing breeding pigs with raw forage (tce)

	Gap of bio-mass energy	Commercial energy consumption in all County	Gross out-put value of farming	Gross output value of town and village enterprises	All GDP
2005	−13,130	−8375	+2833	+17,411	+26,360
2010	−8140	−5214	+2174	+16,840	+17,440
2015	−197,630	−14,996	+4342	+40,970	+61,450

Table 7
Economic and energy benefits on saving energy in township and village enterprises

	Farming		Town and village enterprises		City enterprises		All County		Gap of biomass energy
	Gross output value (10,000 yuan)	Energy consumption (tce)	Gross output value (10,000 yuan)	Energy consumption (tce)	Gross output value (10,000 yuan)	Energy consumption (tce)	GDP	TCE	
2005	+1110	+689	+7410	−7410	+2960	−5940	+12,110	−2900	−5250
2010	+3258	+2033	+26,540	−58,950	+13,930	−31,450	+46,150	−68,500	−9280
2015	+4672	+2932	+39,540	−134,140	+222,780	−67,120	+70,700	−186,800	−18,140

In experiment 4, measures of innovating furnaces of rural industry to increase heat efficiency by 20% are supposed. The results in Table 7 show that as the output value of rural industry is increased, the bioenergy shortage will be decreased. This indirectly speeds up the development of farm production.

There were only 16,800 biogas digesters in the county, the common rate of utilization of which is 67.5% in 2000. Through training the technicians, enforcing management and providing a series of services for biogas digester users, we helped increasing the rate of utilization to 90% in experiment 5. Tables 8 and 9 provide a comparison between the energy and economic benefits after the improvement and those before. Because the increase of the output of marsh gas can bring about the changes in distribution of energy and capital, countryside industry can acquire more commercial energy supply and thus

Table 8
Energy benefits of developing biogas digesters (tce)

	Biogas energy	Gap of biomass energy	Energy consumption on township and village enterprises	Energy consumption on city enterprises	Commercial energy consumption in all County
2005	+371	−140	+200	+30	−90
2010	+593	−410	+500	+120	−269
2015	+582	−980	+1900	+910	−648

Table 9
Economic benefits of developing biogas digesters (10,000 yuan)

	Gross output value of farming	Gross output value of town and village enterprises	Gross output value of city industry	All GDP
2005	+8	+50	+20	+78
2010	+16	+140	+60	+220
2015	+60	+550	+410	+1080

promote the local economy. It is predicted that the direct and indirect increase of economic benefits in 2015 in Lianshui will be 10.8 million yuan.

Based on the above analyses, some suggestions related to the energy construction of Shouyang County are proposed.

Comparing to 2000, the aim of the year 2015 predicted by the simulation experiments are: two doubling the total output value of the County, in which the agriculture output value will increase by 12%. The bioenergy shortage and commercial energy demand will decrease by 92 and 60%, respectively.

The following tasks are the key of achieving the above goal:

(1) Speed up the ecological agriculture construction taking the increase of soil organic matter content and agriculture output the key; popularize high efficiency energy-saving stoves: develop biogas to promote the multi-level utilization of bioenergy and increase the amount of organic matter returned to fields. At present, many difficulties exist during the development of biogas utilization in rural areas in Jiangsu, which may result from:
   (a) the increasing utilization of LPG;
   (b) big initial investment of biogas digester (more than 1000 RMB yuan for a biogas digester of 3–4 m^3);
   (c) unstable output of biogas;
   (d) difficult in removing the wastes;
   (e) difficult to obtain raw materials due to decreasing size of households;
   (f) difficult in obtaining place for biogas digester building due to less land available.

It is suggested that stable development of biogas projects be made in regions with good conditions, and large or medium sized biogas projects and biogas purification projects be developed in well-developed regions.

(2) Adjust the rural living energy structure. The key point is to change cooked pig feed into raw feed and mixed feed to make pig feed commercialized gradually.
(3) In industry itself, energy saving should be done from three aspects-structure, management and technology. Those furnaces of high-energy consumption but low output in rural industry must be obsolete progressively.
(4) The County financial organ should allocate some financial resources for the construction of Commercial energy base so as to prevent the economic contraction caused by the coal mine reducing or remitting tax are expected in energy construction.

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